Appendix P.
Setting the SAV/Water Clarity Criteria Based Sediment Allocations

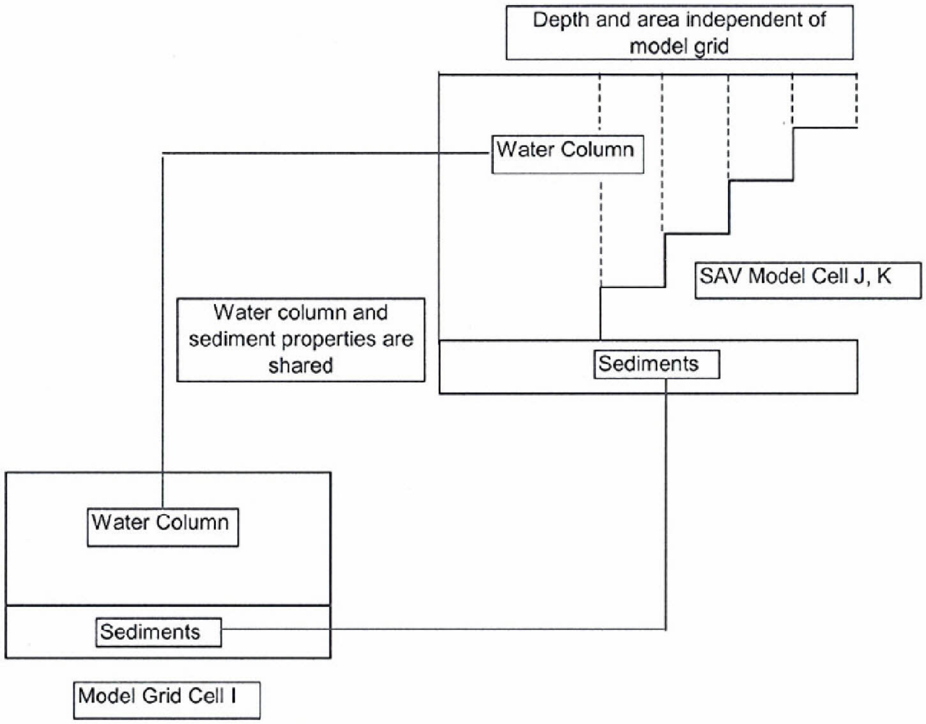
Introduction

The scale of the Chesapeake Bay Program partnership's models extend from the extreme of the continental scale of the Community Multiscale Air Quality Bay Airshed Model and watershed-wide scale of the Phase 5.3 Bay Watershed Model to the other extreme of the narrow ribbon of shallow water adjacent to the Bay's more than 11,000 miles of tidal shoreline. The ribbon of shallow water of 2 meters or less in depth is the region where the jurisdictions' submerged aquatic vegetation (SAV)/water clarity criteria are applied to assess protection of the shallow-water bay grass designated use. This region of a convoluted shoreline is spatially and temporally more heterogeneous than the rest of the Chesapeake Bay Water Quality and Sediment Transport Model (WQSTM) domain covering the open and contiguous waters of the Chesapeake. Episodic loads from shoreline erosion, resuspension, and watershed inputs all transit this narrow band of land and water interface.

The challenge of assessing SAV and water clarity criteria at these scales has only recently been taken up by the Chesapeake Bay Program partnerships in the past 5 years. Monitoring, modeling and research in these shallow-water systems is in its relative infancy compared to the more mature environmental science surrounding dissolved oxygen in eutrophic estuarine ecosystems. In addition, while moving toward these finer scales, the retention of system-wide representation of loading sources, boundary conditions must be preserved.

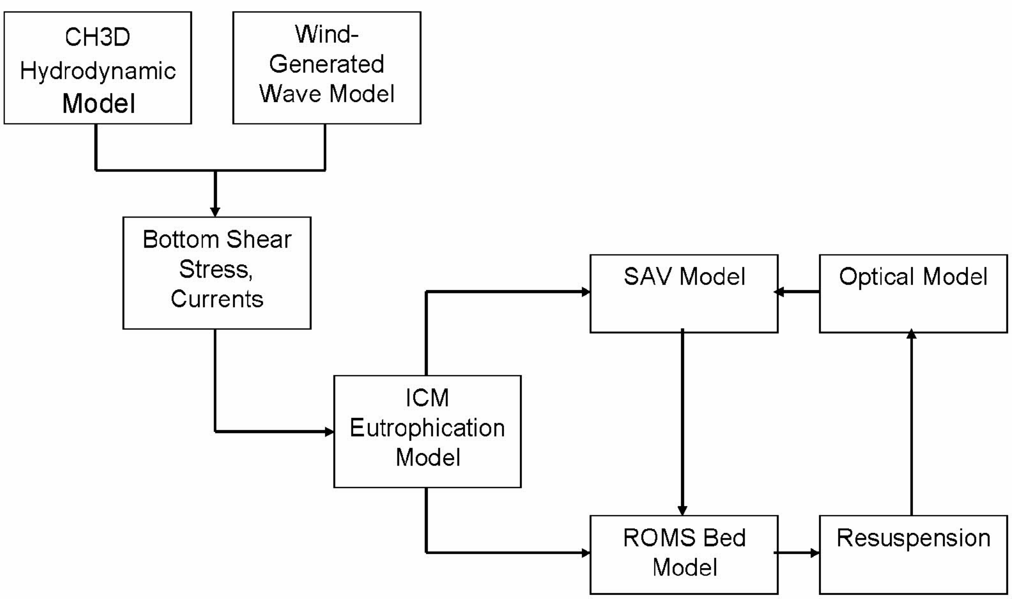
Key Model Refinements in Simulating Water Clarity-SAV

The Bay Water Quality Model used in setting the 2003 Chesapeake Bay nutrient and sediment allocations (Cerco and Noel 2004; Linker et al. 2000; Cerco et al. 2004) was refined to include full sediment transport of four classes of inert particulates approximating the settling and transport behavior of sand, silt, clay, and a sediment fraction of slowly settling clay. The resulting Chesapeake Bay WQSTM was capable of resolving turbidity maximum zones in the Bay and appropriately setting the boundary conditions for the shallow water region of the SAV/water clarity criteria. Resuspension of sediment was generated by currents, both tidal and residual, and by waves. Additional refinements included high resolution at half-meter depths of the shallow-water SAV growth areas (Figure P-1), an advanced optics model of underwater light attenuation, improvements to the SAV simulation, and refinements to shoreline erosion. Those model refinements and additions are shown schematically in Figure P-2.



Source: Cerco et al. 2010

Figure P-1. A schematic of the half-meter depths of the SAV sub-grid unit cells mapped to the WQSTM grid cell, which provides light attenuation and other model state variables the SAV growth cell.

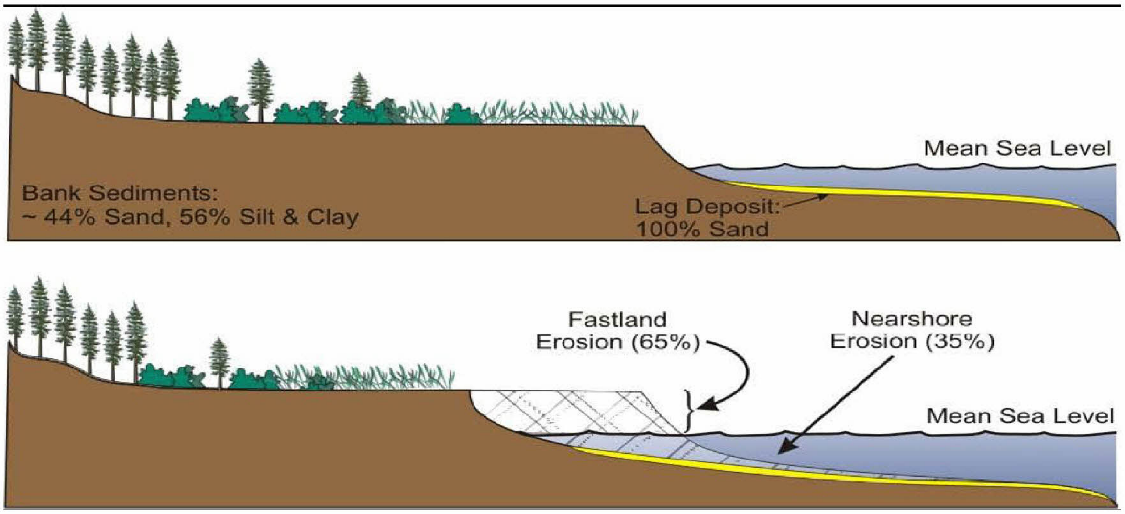


Source: Cerco et al. 2010

Figure P-2. A schematic of the WQSTM refinements applied for the simulation of the SAV/water clarity water quality standard.

Refinements to Shore Erosion Estimates

Consistent temporal and spatial data for erosion rates, bank heights, shoreline protection, and sediment type were needed for the entire Chesapeake Bay to better estimate the role of shoreline erosion in the overall sediment budget (Hennessee et al. 2006; Hardaway et al. 1992). The refined shoreline sediment load estimates included both bank load (e.g., fastland erosion) and nearshore erosion (Figure P-3). Spatially explicit erosion rates by *reach* that allowed for variance with bank height, shoreline orientation, and sediment composition were calculated. Best estimates of the actual shoreline lengths were used, including reduced erosion rates for enclosed minor inlets where reduced wave and current erosion would be expected. The different shoreline loading estimates were then incorporated into the appropriate WQSTM cells.



Source: Hopkins and Halka 2007

Figure P-3. Example of fastland and nearshore components of the shoreline sediment loads.

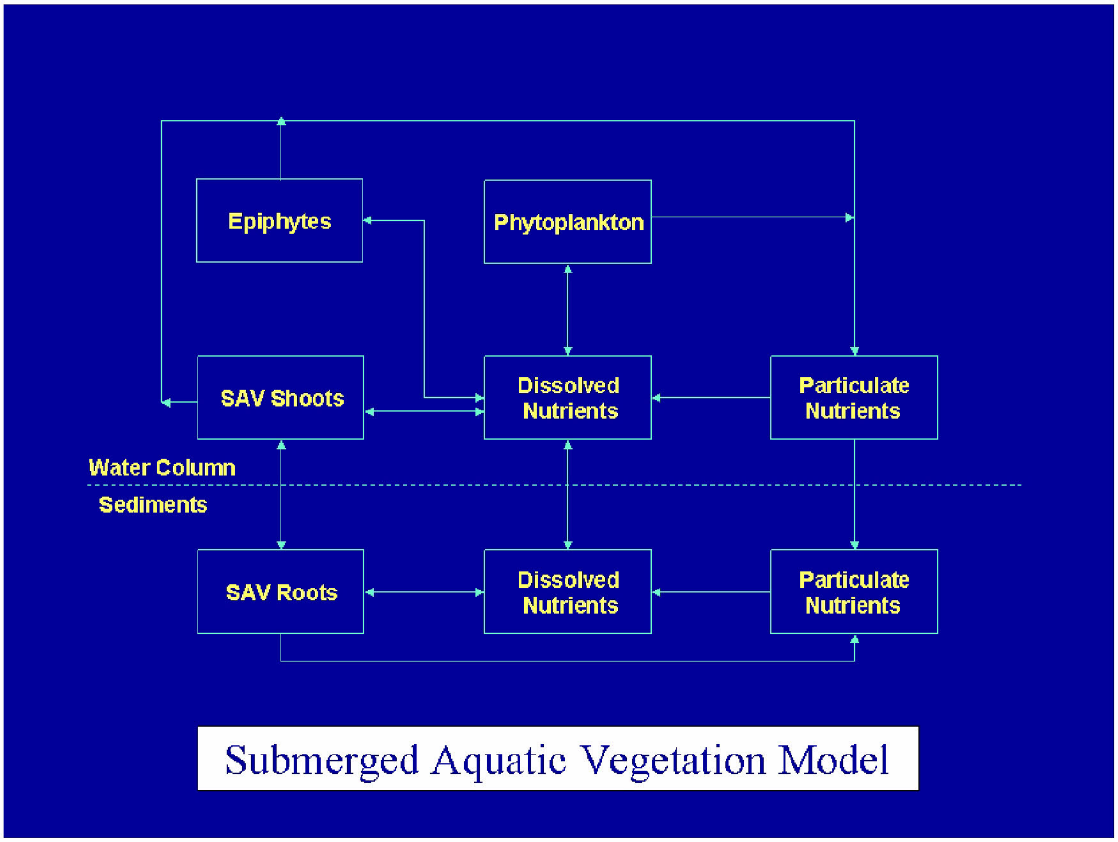
For unprotected shorelines the shoreline erosion computation was as follows:

- Eroded Fastland Volume = Shoreline Length × Elevation × Erosion Rate/Day
- Total Eroded (Fastland + Nearshore) = Fastland Mass / 0.65
- Eroded Silt/Clay Mass = Total Eroded Volume × Bulk Density × Silt Clay %
- Different silt/clay proportions for bank and marsh sources (Applied to Maryland portion tidal shoreline only)
- Different silt/clay proportions for north and south banks of each major river (Applied to Virginia tidal shoreline only)

For protected shorelines everywhere, the assumption was that fastland erosion was eliminated, but that nearshore erosion continued. Nearshore erosion was estimated for protected shorelines by using adjacent or nearby unprotected shoreline.

Simulating SAV

The unit SAV simulation computes SAV density (mass / unit area) as a function of irradiance and nutrients for SAV shoot and roots as shown in Figure P-4. Irradiance and epiphytes are calculated separately, and the SAV model fully interacts with water column and bed sediments (see Figure P-4).



Source: Cerco 2009

Figure P-4. The Chesapeake Bay WQSTM's SAV unit model.

The current simulation of SAV considers light to be the sole determinant of SAV abundance, but other factors such as composition of bottom substrate, SAV community structure, and seed bank availability are significant. Those factors are not explicitly simulated in the WQSTM but are accounted for via an empirical *probability of success.*

The probability function was empirically set to best represent SAV biomass under current nutrient loads and adjusted to improve the probability of SAV growth under conditions that are more representative of mid-1900s Chesapeake nutrient loads (Hagy et al. 2004). The use of the empirically set probability function for SAV allowed appropriate SAV levels to best simulate water clarity, which was solely used to assess the water clarity criteria. Moving forward, in the next generation of the Bay Model, the probability function will be replaced with salient first principal forcing functions.

Process of Assessing the Water Clarity-SAV Criteria

Three methods are used to assess attainment of the Bay jurisdictions' SAV/water clarity water quality standards. Any one of the following three methods can be used to determine whether the SAV and water clarity goal is achieved. The SAV/water clarity criteria assessment applied to the Bay WQSTM scenario output is always on the combined SAV and water clarity criteria assessment method.

Using only acres of SAV coverage: A segment attains the goal if the SAV acreage of single best year in the segment is met in the preceding 3 years (including the current year) (USEPA 2003).

Using only water clarity acres: A segment attains the goal if the single best year water clarity acreage in the preceding 3 years exceeds 2.5 times the SAV restoration acreage. The water clarity acres for a year are assessed on the basis of the arithmetic mean of monthly water clarity in the criteria months that meets the water clarity criteria (see Section 3.1.4, Table 3-5 of the TMDL Report) (USEPA 2007).

Using combined SAV and water clarity achievement: This method considers both the achieved SAV acreage and water clarity acre in a segment. In the assessment, the water clarity acre can be converted to an SAV-equivalent acre by dividing the water clarity acre by 2.5, which will be credited along with the SAV coverage estimated by regression model.

Estimating SAV/Water Clarity in a WQSTM Loading Scenario

In the combined SAV and water clarity assessment, both the SAV acres and water clarity acres need to be estimated in load-reduction scenarios. The light extinction coefficient, *Ke*, is the metric used to measure water clarity. The Ke in a load-reduction scenario is estimated using the Chesapeake Bay WQSTM. The SAV area in a load reduction scenario is estimated from a regression model.

Ke Assessment by the WQSTM

The simulated Ke in the WQSTM is based on the amounts of simulated clay, silt, sand, organic particulates, and dissolved organic matters in a model cell. Because the simulated Ke is an imperfect representation of the observed Ke, a data-correction method is used to obtain an adjusted scenario Ke in each shallow cell for the target loading scenario. While several more sophisticated data correction methods were tried, a simple proportional adjustment of the shallow-water Ke to the nearest observed water quality monitoring station was found to provide the best shallow-water data correction as determined by independent, shallow-water monitoring sites.

The shallow-water bay grass designated-use habitat is considered the are located between the 2-meter depth contour and the adjacent shoreline. A segment consists of Bay WQSTM cells. Because of inconsistency between the model cell boundary and the 2-meter contour area, EPA remapped and extended the model cells to cover tidal water up to the shoreline, and subdivided the area into 0–0.5 meters, 0.5–1.0 meters, 1.0–1.5 meters, and 1.5–2.0 meter depths. For each half-meter contour area, EPA applies corresponding Ke criteria (see Section 3, Table 3-5). Note that the areas of defined no-growth zone are excluded from the cell/segment area in the assessment.

Credit of SAV Area Based on Observed SAV Area

The projected SAV acreage in a target scenario is based on a regression of observed SAV in the Bay segments which, together, compose the major tributaries and the nutrient and sediment loads from each corresponding land basin (i.e., the major subwatershed) of the Chesapeake Bay watershed, which provides loads to the collective set of segments (Table P-1).

Through the Baywide SAV aerial survey, the partners have access to annual SAV distribution and abundance data for almost every year in the past 30 years. The attached Excel file, Appendix P SAV Coverage 1971-2009 Spreadsheet.xls, shows observed SAV for Bay segments in 1971-2009. The observed SAV areas from 102 segments are aggregated into SAV areas for the 8 tidal basins for each year.

Total nitrogen (TN), total phosphorus (TP), and total suspended sediment (TSS) loads from the 8 major basins are estimated from the Phase 5.3 Chesapeake Bay Watershed Model's progress scenarios under years 1985, 1987, 1992, 1998, 2002, 2005, 2007, and 2009 management conditions.

Linear regression of SAV versus load of TN or TP or TSS, respectively, is conducted for each basin, yields

$$\text{SAV} = m\ \text{Load} + b$$

where, coefficient m is the slope and b is the intercept from the linear regression. The results are presented in Table P-1.

For individual basins, we use the regression of SAV with Load component TN or TP or TSS, which has the highest R2 of regression.

The Bay TMDL's critical period of 1993–1995 is our reference for the TMDL. The load in the reference year for each basin can be estimated from Bay Watershed Model calibration, and the corresponding SAV is known from the observation. They also have the relationship

$$\text{SAV\_ref} = m\ \text{Load\_ref} + b.$$

A projected SAV of the basin in a load reduction scenario is calculated as follows:

$$\text{Proj\_SAV} = m\ \text{Proj\_load} + b$$

Therefore, $\text{Proj\_SAV} - \text{SAV\_ref} = m\ (\text{Proj\_load} - \text{Load\_ref})$.

We can calculate the ratio

$$\text{Rate} = \text{Proj\_SAV} / \text{SAV\_ref} = (\text{Proj\_SAV} - \text{SAV\_ref}) / \text{SAV\_ref} + 1 = m\ (\text{Proj\_load} - \text{Load\_ref}) / \text{SAV\_ref} + 1 = (m\ (\text{Proj\_load} - \text{Load\_ref}) + \text{SAV\_ref}) / \text{SAV\_ref}$$

Thus, the projected SAV of this basin for the target loading scenario can also be estimated by

$$Proj\_SAV = Rate \times SAV\_ref.$$

EPA assumes that the rate calculated from a major river basin is applicable to individual Bay segments contained within that basin. That rate is then used to calculate projected SAV in the reference hydrology year for each Bay segment within that basin:

$$Proj\_SAV\ (seg) = Rate \times SAV\_ref\ (seg).$$

The projected SAV in segments is then used for SAV credit in the assessment.

Table P-1. Results of linear regression of SAV versus TN, TP, and TSS loads for 8 major basins

Basin	Component	R2	Slope	Intercept
Susquehanna	TN	0.8983	-4.16E+02	6.43E+04
Susquehanna	TS	0.8049	-2.77E+01	9.11E+04
Susquehanna	TP	0.6847	-8.54E+03	5.12E+04
Potomac	TN	0.9068	-2.85E+02	2.82E+04
Potomac	TS	0.8769	-2.13E+01	6.83E+04
Potomac	TP	0.8449	-1.28E+04	7.04E+04
York	TN	0.0468	1.09E+03	1.79E+03
York	TS	0.8948	-8.81E+01	2.65E+04
York	TP	0.7539	-9.38E+03	1.79E+04
Eastern Shore	TN	0.1615	-1.87E+03	7.69E+04
Eastern Shore	TS	0.5769	-2.29E+02	1.20E+05
Eastern Shore	TP	0.3518	-2.18E+04	8.09E+04
Rappahannock	TN	0.5900	-6.93E+02	6.57E+03
Rappahannock	TS	0.5425	-8.42E+00	7.88E+03
Rappahannock	TP	0.6609	-5.44E+03	7.68E+03
James	TN	0.9624	-8.54E+00	3.81E+02
James	TS	0.8763	-3.59E-01	5.89E+02
James	TP	0.7467	-3.27E+01	2.21E+02
MD Western Shore	TN	0.5437	-2.35E+02	6.11E+03
MD Western Shore	TS	0.7106	-4.79E+01	1.49E+04
MD Western Shore	TP	0.5361	-3.50E+03	5.17E+03
Patuxent	TN	0.5940	-2.02E+02	9.31E+02
Patuxent	TS	0.5693	-3.66E+00	7.66E+02
Patuxent	TP	0.3253	-1.38E+03	6.89E+02

Assessing Attainment of the SAV/Water Clarity Standard

Before the assessment, EPA converted the SAV restoration goal acreage (see Section 3.1.4, Table 3-6 of the TMDL Report) with a factor of 2.5 to establish the water clarity acre for each Bay segment.

For individual months, EPA compared the monthly average Ke in a cell at four depth-interval areas (0–0.5, 0.5–1.0, 1.0–1.5, and 1.5–2.0) with the applicable water clarity criterion for the four application depths (i.e., 0.5, 1.0, 1.5, and 2.0), respectively. If it meets the criterion for that depth, the area is accounted. Adding the area achieving the water clarity criterion for each depth of all cells in the segment, yields the total area achieving the water clarity criterion for the month. Averaging (using arithmetic mean) the monthly achieving areas in the criteria months (i.e., SAV growing seasons—see Section 3.1.4, Table 3.5 of the TMDL Report) produces the water clarity acres for that year for each segment. If the water clarity acre is smaller than the SAV area, EPA uses 2.5 of the assessed SAV area as the total water clarity acre from the combined SAV/water clarity assessment in the year. If the water clarity acre is greater than the SAV area, EPA credits 1.5 of the assessed SAV area, into the total water clarity acre of this year for this combined SAV/water clarity assessment.

Finally, the water clarity acre in single best year of the 3 consecutive assessment years (i.e., 1993–1995 hydrology years) is regarded as the achieved water clarity acreage. If the achieved water clarity acre was greater than the water clarity acre goal (i.e., 2.5 times SAV acre goal), the combined SAV/water clarity criteria were projected to be achieved in this segment under model loading scenario. Otherwise, i.e., the achieved water clarity acre is less than the water clarity acre goal, a percent violation is calculated as follows:

$$100 \times (\text{water clarity acre goal} - \text{water clarity acre}) / \text{water clarity acre goal}.$$

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